Catchy title

A trifold approach to quantify the effect of a common olfactory lure on the detection probability of urban mammals during camera trapping

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# Introduction

Humans have trapped mammals for millennia. While the motivations for mammal trapping are varied, our predecessor’s trials and tribulations have distilled much wisdom to beguile wildlife into snares, leg-hold traps, or cages. One suggested technique to bolster trap efficacy is the use lures or bait. The motivation for such an approach stems from the notion that lures or bait will engage a species sense of smell, sight or hearing and therefore increase the chance a target species investigates a trap (as reviewed by Schlexer 2008). Indeed, the overall success of a trapping operation may well depend on the type of lures or baits used, and a plethora of commercially available lures and baits exist for live-trapping purposes (Schemnitz 2005, Schlexer 2008).

For research purposes, motion-triggered camera traps (hereafter camera traps) have become an important alternative to livetrapping (refs). Camera traps allow researchers to passively sample multiple locations simultaneously and do not require the physical restraint of an organism, thereby eliminating the chances of trap-mortality or injury. Further, camera traps can be used to answer many ecological questions about the distribution and abundance of wildlife (refs). Yet, for an animal to be caught (i.e., photographed) it must move in front of a deployed camera trap, and camera trapping surveys must therefore look for ways to increase the detectability of species via study design (O’Connel et al. 2011, Hofmeester et al. 2019). As a result, both lures and bait have been suggested as ways to increase the likelihood of detecting species that occupy an area of interest (refs). However, the reasoning behind the use of lures or bait is mostly grounded in custom rather than quantifiable effectiveness (refs).

Studies that have quantified the effect of lure

Studies that have quantified the effect of lure or bait typically compare detection probability across sites that either do or do not have lure in view of a camera trap (Garrote et al. 2012, Bischof et al. 2014, Rocha et al. 2016, Suárez-Tangil & Rodríguez 2017). Such a study design makes it difficult to estimate the effect of lure given that a species abundance likely varies between locations, which can also influence detectability (McCarthy et al. 2013). Furthermore, lure may influence species detectability in a variety of ways, which to date has been little discussed (REFS). While most studies compare the number of days a species was detected in the presence or absence of lure to determine its effect, this is not likely the only metric that should be used. For example, lure could reduce the amount of time it takes to detect a species (REFS), or simply increase the amount of time an organism spends in front of a camera trap thereby increasing the number of photos (Refs).

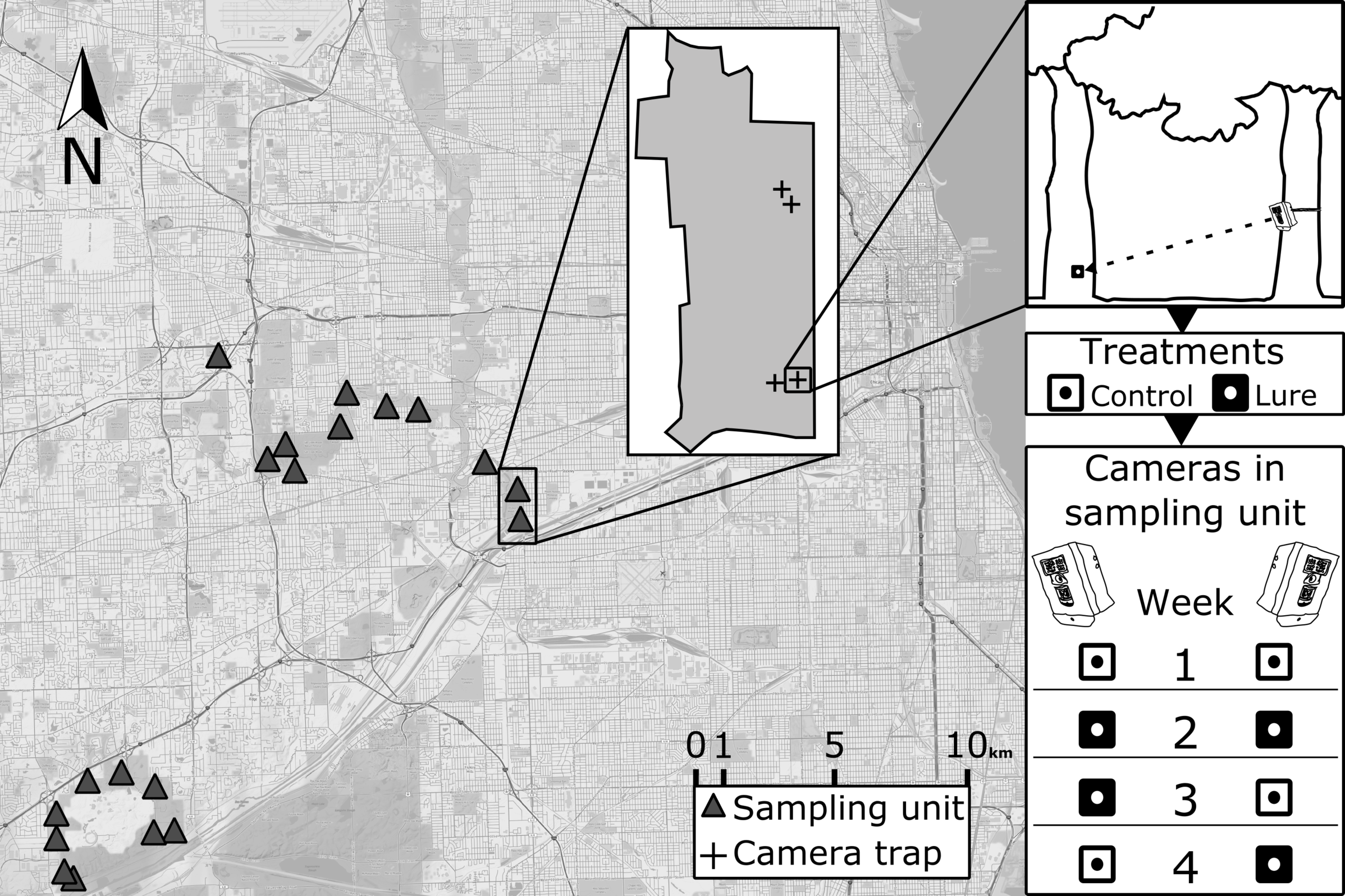
In this paper we use a trifold approach to quantify the effect of a common olfactory lure on a suite of mammalian species in natural areas throughout Chicago, Illinois, USA. Our study design differs from others in that we deploy two camera traps per sampling unit, spaced apart by 100 m, over a 28-day period to experimentally assess if lure can modify the detectability of a species both within and between sites. To do so, we changed lure treatments every 7 days by placing either a lure or a no lure control in view of each camera following a full factorial design. This arrangement allowed us to quantify if lure increases the chances of detecting a species as they may be drawn more often to a camera that has lure relative to a nearby camera that does not. To more fully explore how lure many influence species detectability, we sought to answer these three questions:

1. Does lure increase the number of days a species is detected?
2. Does lure decrease the amount of time to first detection?
3. Does lure increase the number of photographs of a species?

# Methods

## Study area and site selection

## This study was conducted in northeastern Illinois within the Chicago metropolitan area (hereafter Chicagoland). The third largest metropolitan area in the United States, Chicagoland contains an estimated population of 9.5 million residents, 28% of which live within the city of Chicago itself (U.S. Census, 2013a). For this study we randomly selected 20 locations within forest preserves southwest of downtown Chicago in DuPage and Cook County. These locations (hereafter sampling units) were a minimum of 1 km apart from one another, and therefore a sufficiently large forest preserve could host multiple sampling units (Figure 1). Chicagoland forest preserves were selected instead of other types of urban green space (e.g., city parks) because they have the greatest mammalian species richness and highest occupancy rates of common mammals (Gallo et al. 2017). Therefore, Chicagoland forest preserves likely represent the ideal green space to quantify the effect of lure on mammal detection probability.



**Figure 1.** A total of 20 sampling units were selected inside forest preserves to the southwest of downtown Chicago, Illinois. Each sampling unit consisted of two camera traps separated by 100 m. During each week of the 4-week study a different combination of lure or non-lure control was placed in view of the two camera traps within a sampling unit.

## Experimental design

Each sampling unit consisted of two Bushnell motion-triggered infrared Trophy Cameras (hereafter camera traps). After placing the first camera trap as close as possible to a sampling units location, we walked 100 m in a random direction to set the second camera trap. Additionally, camera traps were not placed along evident game trails. For settings, Camera traps were put on normal sensitivity to take a single photo with a 30 second delay between capture events so long as it was being triggered (for full specifications see supplemental material). Camera traps were placed inside a metal security box and then strapped and cable locked to a tree 130 cm from the ground. Following this, camera traps were angled at a downward trajectory with sticks towards a given experimental treatment, which was located roughly 2.5 – 5.8 m from the camera trap.

We had two treatments for this study, a lure treatment and a non-lure control. For the lure treatment, we used a white 2.5 cm plaster disk impregnated with a synthetic fatty acid scent (FAS; Pocatello, YEAR), which is a commonly used olfactory lure advertised to increase the detectability of mesocarnivores, especially coyote (REFS). The non-lure control was a piece of white cardstock cut to an identical size as the FAS disk. Treatments were contained within a 7.5 cm x 7.5 cm mesh pouch and nailed to a tree approximately 30 cm from the ground (Figure 1). The non-lure cardstock and mesh control was used to account for the placement of a novel object in view of a camera when using lure (i.e., a visual control).

For this study, camera traps were deployed for 28 consecutive days between August 27, 2018 and September 25, 2018. This 28-day season was divided into four-week long sessions. Treatments were changed every week following a full factorial design for the two camera traps per sampling unit (Figure 1). Briefly, for camera traps A and B in a sampling unit, both received non-lure controls on week 1, which were then exchanged for lured pouches on week 2. On week 3, camera trap A received a new lure pouch while camera trap B was given a non-lure control. The opposite occurred for week 4: camera trap A received a non-lure control while camera trap B received a lure pouch (Figure 1). Memory cards were replaced every week while batteries were replaced on all camera traps at the beginning of week 3 (or as needed otherwise). To ensure accurate identification of species in an image, pictures were identified two times by separate individuals (GB and MF). If there was disagreement between identifications on a given image, the photo was assessed a third time to determine the correct identification. The date and time of each photo was collected in the exif data tied to an image.

## Statistical analysis

We fit three separate hierarchical occupancy models to all species with sufficient data. For simplicity, we explain these models for a single species. In the three models, we assume the occupancy status of a species does not change over the 28-day sampling period and that the probability of occupancy does not vary between sites. Thus, the probability of occupancy, *ψ*, at *s* in 1,…,*S* sites is the following Bernoulli process

where *zs* is a random binary variable that represents the occupancy status of a species. If the species is present *zs* takes the value of 1 and is otherwise 0. Such a model is no different than the latent state of an intercept-only occupancy model, which we assume is adequate given the proximity of and similarity between natural areas sampled in this study.

### Observation model 1: Does lure increase the number of days a species is detected?

Our first model assumes that days within a sampling week are repeat surveys in which a species may be detected given its presence. This is the most traditional formulation of a hierarchical occupancy model (ref). For each of the two cameras, *c*, deployed at a site and *k* in 1,…,4 weeks of sampling we can model the effect of lure as the following Binomial process:

Where *ys,k,c* are the number of days a species was detected at site *s* on week *k* at camera *c*, *js,k*are the number of days sampled at site *s* on week *k*, and *ps,k,c* is the probability of detecting a species given their presence (i.e., *zs* = 1). We can incorporate the presence of lure on *ps,k,c* via the logit-link function such that

Here, is the log odds a species is detected without lure, is the log odds difference in detection given the presence of lure, is an indicator variable which takes the value 1 when lure is present at a camera, and is a site-level random effect to account for variability that may exist between sampling locations not attributed to lure.

### Observation model 2: Does lure decrease the amount of time to first detection?

Instead of increasing the number of days a species investigates a camera, lure may decrease the amount of time it takes to detect them for the first time (Bischof et al. 2014). To quantify this effect, we instead treat data collection as a continuous time process. Thus, let the response variable of this model, , be the continuous number of days to first detection (i.e., the amount of time it takes each week to collect the first image of a species per camera). However, if a species is present at a site but not detected after 7 days when treatments are changed there is uncertainty about how long it would take for the species to be photographed. To account for this, we model as a censored exponential random variable. Let *Tmax* represent the maximum amount of time a lure treatment is placed in front of a camera trap (i.e., *Tmax* = 7 days). Following Kery and Royle (2016), the continuous time-to-detection observation model is

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Here, is an indicator function which takes the value 1 if a species was not detected in a given week at a camera trap. Thus, equals 1 if a species is present but went undetected or if they were not present (i.e., *zs* = 0). When this occurs, . Otherwise, equals 0 and we sample from the Exponential distribution to estimate the inverse scale parameter from the right-censored data. To estimate the effect of lure on this rate we employ the log link function

We use a similar parameterization to the linear in model 1 (Eq. X), except the coefficients in this model are on the log-scale. Further, these coefficients estimate the expected time between detection events in the presence or absence of a lure, all while controlling for variability between sites not attributed to lure via the site-level random effect .

### Observation model 3: Does lure increase the number of photographs of a species?

Finally, lure may increase the number of photographs taken of a species if it increases the amount of time they spend in view of a camera. This may be advantageous if a study species can be identified to an individual level by their markings, such as a leopard’s spots, which is easier to do with multiple images (refs). Here, let be the number of images collected of a species as site *s*, week *k*, and camera *c*. We then model the number of images collected as the following Poisson process

where and are the same as before while is a rate parameter which estimates the average number of photos expected per day given a species presence. Similar to model 2, is used to control for the observational treatment window length. To incorporate the effect of lure we again use the log link, as we did with model 2:

### Specification of priors and model fitting

We took a Bayesian approach to estimate the parameters of our models. For all models, we used an uninformative Beta(1,1) prior for the probability of occupancy, *ψ*. For the observational process of each model, the choice of priors depended on the link function used. For model 1, which uses the logit-link, we followed the suggestions of Gelman et al (2008) and gave the intercept, *a0*, a Cauchy(0, 10) prior while the lure effect parameter (*a1*) received a Cauchy(0, 2.5) prior. For models 2 and 3, the log-link intercept and lure effect parameters received uninformative Normal(0, 10000) priors. Finally, random effects from all models were drawn from Normal(0, σ) distributions where σ ~ Gamma(0.001, 0.001).

Models were written and executed in JAGS version 4.3.0 (Plummer 2003) through program R version 3.5.2 (R Core Team 2018) via the runjags package (Denwood, 2016). Following a 1,000 step adaptation phase models had a burn-in period of 50,000 steps. After the burn-in, parameters were sampled a total of 300,000 times across 6 chains. MCMC chains were thinned by 5. Model convergence was assessed by visually inspecting trace plots and ensuring that Gelman-Rubin diagnostics for each parameter were < 1.10 (Gelman et al. 2014). Significance of the estimated regression coefficients was calculated by assessing if 95% credible intervals did not overlap 0.

# Results

Over the course of this study 1,110 functional camera days out of a possible total of 1,120 (28 days \* 40 cameras) were collected. In this period a total of 6,110 images were collected of 12 different species. Eight species had enough data to fit the three models: coyote (*Canis latrans*), eastern chipmunk (*Tamias striatus*), eastern cottontail rabbit (*Sylvilagus floridanus*), eastern gray squirrel (*Sciurus carolinensis*), fox squirrel (*Sciurus niger*), raccoon (*Procyon lotor*), Virginia opossum (*Didelphis virginiana*, hereafter opossum), and white-tailed deer (*Odocoileus virginianus*). The remaining four species that had insufficient data were the American mink (*Neovison vison*), long-tailed weasel (*Mustela frenata*), southern flying squirrel (*Glaucomys volans*), and striped skunk (*Mephitis mephitis*). Eastern gray squirrel were photographed the most over the survey, totaling 1,917 pictures across all 20 of the sites. Of the species that could be analyzed, eastern cottontail rabbit were detected the least, totaling 72 pictures across 9 of the 20 sampled sites.

## Does lure increase the number of days a species is detected?

Without lure, daily detection probability varied greatly between species (Figure 1). Coyote, for example, had a 5.77% (95% CI = 2.85 – 9.21) probability of being detected each day, which did not increase when lure was placed in front of a camera (Figure 2). Raccoon and gray squirrel had the highest detection probabilities without lure, which were respectively 46.09% (95% CI = 36.69 – 55.00) and 47.89% (95% CI = 36.45 – 58.49). On average, the presence of lure increased raccoon and gray squirrel detection by roughly 5%, but 95% credible intervals of this effect bounded zero (Figure 2). Overall, the presence of lure significantly increased the number of days two species were detected: opossum and chipmunk. Opossum detection probability increased by 8.20% (95%CI = 3.32 – 13.36) when lure was present to a total daily detection probability of 25.08% (95% CI = 18.03 – 32.46). Lure had a lesser effect on chipmunk detection probability, which increased by 4.76% (95% CI = 0.38 – 10.40). There was some indication that the presence of lure decreased the number of days white-tailed deer and eastern cottontail were detected, but this effect was not significant (Figure 2).



**Figure 2.** Lure had a marginal, but varying effect on the number of days species were detected. The left plot illustrates the daily probability of detecting a species when no lure was in front of a camera. The right plot illustrates how a species detection probability on the left changes given the presence of lure. Vertical solid lines are median estimates which are plotted over the posterior distribution that fell within the associated 95% credible interval.

## Does lure decrease the amount of time to first detection?

Without lure, the expected number of days to first detection ranged from 2.21 (95% CI = 1.12 – 3.69) for gray squirrel to 20.75 days (95% CI = 9.63 – 45.37) for cottontail rabbit (Figure 2). When lure was placed in view of a camera most species showed a general decreasing trend in the amount of time to first detection (Figure 3). However, credible intervals of this effect bounded zero for all species except the opossum. On average, the expected time to detect opossum decreased by 35.34% (95% CI = 11.13 – 55.83) to 5.57 days (95% CI = 3.73 – 7.81). There was some indication that it took longer to detect both coyote and cottontail rabbits given the presence of lure, but this effect was also not significant (Figure 3).



**Figure 3.** Opossum were the only species to arrive earlier if a lure was placed in front of a camera. The left plot is the expected number of days until the first photograph is taken given a species presence. The right plot is the proportional effect that lure has on the number of days until a photograph is taken, with values < 1 indicating a decrease in the amount of time to first detection. Vertical solid lines are median estimates which are plotted over the posterior distribution that fell within the associated 95% credible interval.

## Does lure increase the number of photographs of a species?

Of the three analyses, more species showed a significant change in the number of images collected given the presence of lure (Figure 4). Two species had more photos taken when lure was present: opossum and raccoon. For opossum the number of images captured increased by a factor of 2.01 (95% CI = 1.66 – 2.38), while the number of images captured of raccoon increased by a factor of 1.15 (95% CI = 1.06 – 1.26). All other species save for the cottontail rabbit had a marginal but non-significant increase in photos given the presence of lure (Figure 4). Cottontail rabbits, on the other hand, were less likely to be photographed given the presence of lure as the number of images collected decreased by a factor of 0.42 (95% CI = 0.25 – 0.62).



**Figure 4**. More images were collected of opossum and raccoon while lure was present, while cottontail rabbits were photographed less. The x-axis represents the proportional change in the number of photos taken of a species when lure was present. Values > 1 indicate that more images were taken.

**Discussion**

Our trifold approach to quantify the effect of lure on urban mammals provided evidence that the presence of lure may provide a subtle increase to species detectability in varying ways. Save for rabbits and deer, most mammals trended towards being detected on more days or earlier in time given the presence of lure, though 95% credible intervals of this effect often included zero. Overall, opossum had the largest response to lure over all three analyses. By placing lure in view of a camera opossum are detected across more days of a survey (Fig. 2), in a shorter amount of time (Fig. 3), and the number of opossum images is doubled (Fig. 4). Raccoon, the only other mesocarnivore we observed a response to the presence of lure, was photographed 15% more but did not arrive any earlier to a camera or get detected across multiple days. Together, these findings indicate that lure may provide some increase in species detectability, but it varies by species and may not be as substantial as expected.

When designing a camera survey, the decision to use lure will greatly depend on the study species, lure type, study goals, and the time of year camera traps are deployed (for a review see Long et al. 2008). In our study, for example, lure may not be necessary to detect these species because they are common and abundant throughout Chicagoland (Gallo et al. 2018). As detectability is partially a function of abundance (McCarthy et al. 2013), lure may not be needed in studies of common species because detection probabilities are already relatively high (Figure 2). Conversely, studies that focus on rare species such as terrestrial carnivores require much more sampling effort per successful detection (MacKenzie & Royle 2005; Shannon et al. 2014). In this case, it may be more beneficial to use lure because any increase in species detectability per survey day has a multiplicative increase in overall detectability:

Given this data generation process it is possible to sample enough days to detect any species with a detection probability > 0 yet doing can create problems when it comes time for analysis. For example, the vast majority of occupancy models assume a species occupancy status within a site does not change over a survey season (i.e., there is site closure). Increasing the number of survey days could violate this assumption, wherein a species colonizes or leaves a site within a sampling season, resulting in biased occupancy estimates (Rota et al. 2009; Otto et al. 2013). Therefore, to not violate assumptions of site closure it may be more beneficial to increase a species detectability instead of the number of repeat visits to a site. While our data illustrate that lure could increase the detectability of some, but not all species, there may be other methods available to researchers to increase detectability. For example, using multiple camera traps to monitor the occupancy status of a single site could increase the number of days sampled while still keeping the overall sampling period short to ensure closure (Stokeld et al. 2016).

Under an occupancy modeling framework estimates of patch occupancy may be positively biased For example, the resulting occupancy estimAs the vast majority of occupancy models assume doing so increases the chances of violating this assumption, which. As the vast majority of occupancy models assume a species occupancy status does not change over a primary sampling period (i.e., the closure assumption). suggesting to increase the number of survey days to raise overall detectability increases the chance of violating

While it is theoretically possible to increase the number of survey days to detect a species, increasing the number of survey days . First, it may be better to sample more sites with fewer repeat surveys (MacKenzie & Royle 2005). Second, when analyzing detection / non-detection data under an occupancy modeling framework, sites are

Therefore, there are only two variables that can be modified to increase the chances of detecting a species at least once. First, a species daily detection probability can be increased. or a survey can the number of survey days can be increased. As a p

Camera traps provide many opportunities to detect a species as they can be left out for long periods to passively sample wildlife populations. Yet

For example, As a marginal increase in species detectability could reduce the number of days a site reduce costs by decreasing the amount of time it takes to detect a species.

1. With our study, we quantified the effect of lure a suite of common urban mammals detection rates. As many of these species are common and abundant throughout Chicagoland (Gallo et al. 2018), lure may not be as necessary given their ecology. Recap of our biggest results, and provide the most generalized findings.
   1. Opossum love lure
   2. Raccoon photographed more
   3. Chipmunk more days
   4. Most mammals trended to being detected more or earlier, save for rabbits and deer.
   5. These findings indicate that lure may provide some increase in detection, but it may not be as substantial as expected. Expected like some preconceived notion thing.
   6. Lure costs time and money, it should have a large effect to blah blah ablh. We did not see that IN OUR STUDY.
2. Given our analysis of looking into detectability in a variety of ways, we were able to observe much more nuanced effects of lure, which may be able to aid with study design.
   1. Raccoon example. Go into hidden lure effect here?
   2. Wouldn’t be able to see this if we only analyzed 1 way.
   3. Considering the sampling window is important
      1. Go into assumptions of occupancy models (shorter window is better to determine occupancy, at odds with being able to sufficiently sample though.)
      2. More cool stuff on how we analyzed the data.
   4. Overall, the detection process can be treated in a variety of ways to better account for the likelihood of detecting species. Add lure tidbits.
3. So do we use lure or not?
   1. Study specific
      1. What species are you studying
      2. What lure are you using
      3. What is your research question? Single vs multiple species (give medication example which shows when lure / bait IS NECESARRY).
      4. Time of year?
      5. Rare or common species?
      6. Lure or bait can be
4. Defense for our “human effect” visiting at sites.
   1. Forest preserves visited by millions of people each year.
   2. We used gloves and tried not to leave our scent.
   3. Therefore we don’t expect this to influence our results.
   4. While weather may have had an influence, sites were all within same region, so if there was an effect it was applied to all sites simultaneously.
5. CAVEATS
   1. We could have added a real “no lure control.” Right now we are only comparing to lure vs visual attractant. Regardless, we found that for most species you could just put a thing in front of a camera and that would be as good as lure.
   2. Figure out how to see if lure brings in species from outside area. Way more difficult.
      1. Saw no effect of lure when one camera in a sampling unit had lure while other did not. The fact we did not see this difference likely indicates that lure cannot have an effect at scales larger than this (for these species). We did see this with opossum though, so it can be very species specific!
   3. Put camera up before sampling begins (novel object, may want to investigate or not). Again, may not matter for our species, but something to think about.
6. Conclusion

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